Performance monitoring of low energy refurbishment in present and future climate

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ABSTRACT

Buildings account for between 20-40% of final energy consumption in developed countries worldwide wide, and the figure is expected to grow at an annual rate of 1.5% at least for the next 20 years. In an effort to reduce operational energy consumption retrofitting of existing buildings is widespread. Often retrofitting focuses on improving the building envelope, adding micro-renewable technology and installation of mechanical ventilation systems. These retrofit measures have an associated embodied energy and embodied carbon. It has been found previously in low energy buildings that using an excessive amount of these types of measures can result in a high embodied energy/carbon that will not be repaid over the service life of the building through savings operational energy/carbon. Measures that focus solely on the reduction of energy consumption can have a detrimental effect on the internal conditions, with a building becoming uncomfortable for occupants. Also the retrofit measures that are commonly implemented are designed for the current climate with little consideration given to the potential effect of climate change.

This paper presents the monitoring and modelling results of a completed low energy retrofit in Northern Ireland. Monitoring results of internal conditions and energy consumption for the first nine months of occupancy are presented. The operational energy was also simulated using dynamic computer modelling. The effect of potential climate change has also been considered with the resulting changes on operational energy and internal conditions discussed.

KEYWORDS: refurbishment (retrofit), life cycle, sustainability, indoor environmental quality.

1. INTRODUCTION

There are number of drivers for the implementation of refurbishment across the UK. The Government has set a legally binding target of an 80% reduction of CO2 emissions by 2050 on 1990 levels. Commitments have also been made to reduce the number of homes categorised as being 'fuel poor', where households have fuel costs that are above average resulting in a residual income below the official poverty line. Traditionally housing stock replacement in the UK is low, with studies estimating that between 60-80% of houses in 2050 are already standing today. Between 1979 and 2009 in the average UK household 62% of energy consumed was used for space heating, with a further 22% on domestic hot water (Department of Energy & Climate Change, 2013a). Whilst some guidance does exist for the improvement of housing energy efficiency there was a lack of practical case studies where houses had undergone extensive refurbishment measures and had monitored results post-occupancy to assess the effectiveness of the measures. As such the Technology Strategy Board, a government agency, provided funding for practical demonstration retrofit projects that were innovative and would significantly reduce energy consumption and carbon emissions. Case studies were to have their performance evaluated post-retrofit using a number of tests and long term monitoring of internal conditions and energy consumption. This paper discusses the monitoring results of one such case study, with these results compared to computer modelling completed in IES-VE software. The model was also re-run with weather files that replicate potential climate change impacts and results are discussed. Further details of this and other case studies are available from the Low Energy Building Database (2011).

2. CONSIDERING FUTURE CLIMATE SCENARIOS

2.1 Climate change projections

Climate change models, based on the conservative assumption of an increase in carbon dioxide atmospheric concentration to 600ppm, predict an increase of 1.5˚C on average mean temperatures by 2050 and an increase of 2-4˚C by 2080 in the UK as summarised by de Wilde & Coley, (2012). Extreme weather events are also more likely to occur with heat-waves and drought expected in summer months and colder and wetter weather in winter months.
For the built environment a number of potential issues have been identified by Hacker & Holmes (2007) & Collins et al. (2010) such as building overheating and the increased use of air-conditioning. As retrofit measures prioritise increasing thermal envelope insulation and improving building envelope air-tightness there may be a risk of exacerbating the effects of climate.
Climate change projections from UKCP09 are generated from three different emissions scenarios and are available for three different years: 2030, 2050 and 2080. The three emissions scenarios which were developed in Special Report on Emissions Scenarios (SRES) produced by the IPCC Intergovernmental Panel on Climate Change in 2000 are based on different rates of economic and social change covering items such as population change, economic growth, technologies and energy intensity of the 21st century.

- High - SRES A1F1
- Medium - SRES A1B
- Low – SRES B1

To take into account the natural variability and uncertainty associated with climate results of whichever emission scenario or year selected UKCP09 presents the projections with the probabilities of a range of possible outcomes. The University of Exeter Centre’s for Energy and the Environment (Eames et al., 2011) have created weather files that can be imported and used in most building simulation software to indicate future climate conditions. Fourteen locations have so far been created, of which Belfast is one, for three future time periods 2030, 2050 & 2080 with two of the emissions scenarios – the low scenario (SRES B1) being neglected given current carbon emissions.

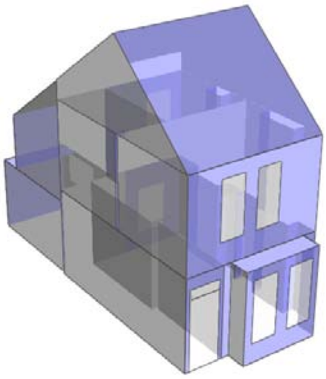
3. CASE STUDY: SOLID WALL VICTORIAN TERRACE HOUSE

3.1 Refurbishment measures implemented

The case study is a mid-terrace red brick house built in 1896 which is located in North Belfast. It is a three storey property built with red brick and is a typical example of Victorian terraces found across the UK. The house consists of three bedrooms, living area, kitchen and bathroom. The retrofit strategy prioritised improving the thermal envelope of the building to reduce heat loss, tightening the building envelope to reduce infiltration heat loss, installing a mechanical ventilation with heat recovery system to reduce ventilation heat loss, replacing appliances with low energy substitutes and the installation of micro-renewables.

External insulation, often the most preferred method of improving the building fabric, was not suitable in this instance as the terrace was a mix of private and social home. The application of an external insulation would also have detracted from the architectural heritage of the building. Instead internal insulation was applied with a cement parge to the masonry walls with additional flanking of phenolic insulation to minimise thermal bridges at party wall junctions. Having no existing insulation the floor slab was removed with a new slab cast on 200mm phenolic insulation. Triple glazing was installed throughout with careful attention paid to minimise thermal bridges by adding the phenolic and closed-cell foam insulation at frame edges. The roof had an air-tight barrier and insulation applied. The retrofit was designed to be as air-tight as possible thus requiring the installation of a mechanical ventilation with heat recovery (MVHR) system to ensure good indoor air quality. Photovoltaic panels ($13m^2$) were installed on the south-facing roof at a 30˚ tilt.

(a) Front of case study house



(b) Case study house model in IES-VE software

Figure 1. Front and model view of case study house.

Integrated Environment Solutions Virtual Environment (IES-VE), a dynamic energy simulation software, was used to model the energy consumption in the house. Modelling inputs are summarised in the Table 1. A local Example Weather Year (EWY) file which contains long term averages of weather conditions were used for simulation of energy consumption.

Table 1. Summary of Case Study House

	Unit	Pre-retrofit	Post-retrofit
Airtightness N_{50} Air-changes per hour	ACH	12.21	0.3
U-values			
Ground floor	W/m^2K	0.48	0.10
Walls	W/m^2K	1.20	0.15
Roof	W/m^2K	2.22	0.10
Doors	W/m^2K	3.0	1.0
Windows	W/m^2K	4.0	0.8

4. MONITORING RESULTS

Monitoring equipment has been installed in the case study house since 2012 but there have been interruptions in data collection due to the malfunction of the third party managed data collection and database. Temperature and relative humidity sensors have been installed in living room, kitchen attic and on the exterior of the house. A CO_2 sensor has also been installed as indicator of indoor air-quality. Gas, electricity and domestic hot water consumption are also measured. All measurements are recorded at 5 minute intervals resulting in large volumes of results. The house has been occupied by a family of three people since the 20th of August 2012 and monitoring data from this date until the 17th of May is presented.

4.1 Temperature and relative humidity results

The assessment criteria used in this paper for a comfortable range of internal temperature, as suggested by Chartered Institution of Building Services Engineers (2006), is between 19-25˚C. Temperature thresholds of 26˚C for bedrooms and 28˚C for living rooms are often used by designers, with a room considered to be ‘over-heating’ if temperatures exceed these more than 1% of the time. Over-heating is not just a function of temperature but is also related to lack of air movement, poor ventilation, building function and continuous spells of hot weather.

According to the World Health Organization Europe (2009) an internal humidity in range of 40 to 70% is considered acceptable for a comfortable environment with the optimum being around 65%. If humidity levels exceed 70% the risk of the formation of house dust mites and airborne fungi is increased. Mould growth is likely on surfaces if surface water activity is over 80% for more than 6 hours of the day. Figure 2 and Figure 3 below show the temperature and relative humidity recorded in four locations, one external sensor and sensors locating on the ground, first and second floor in the living, main bedroom and attic respectively.

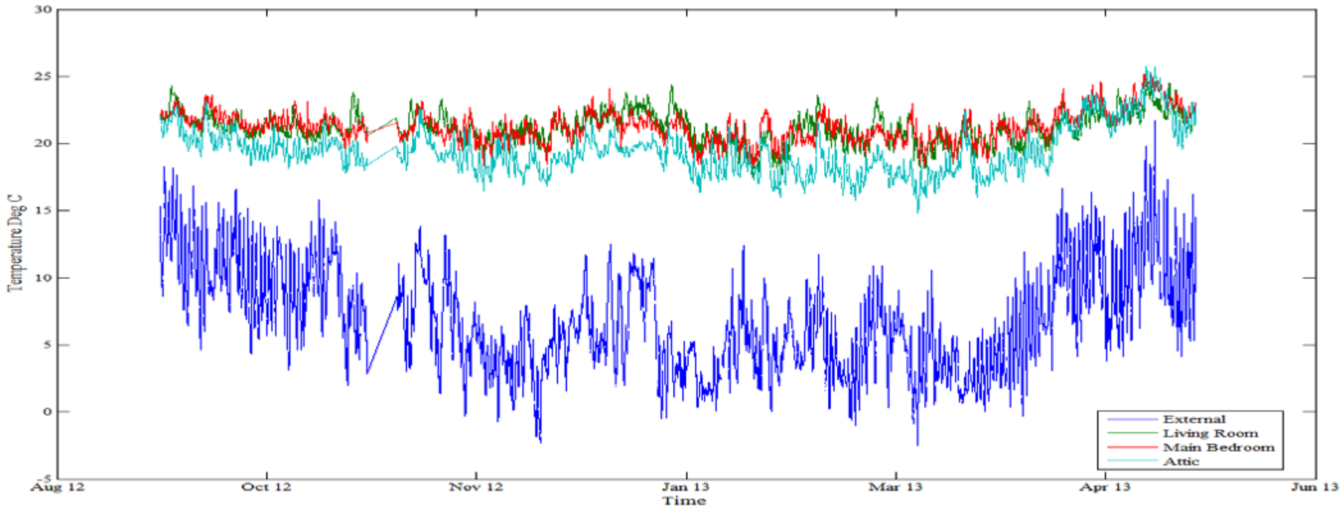


Figure 2. Temperature (Deg˚C) measurements from September 2012 to May 2013

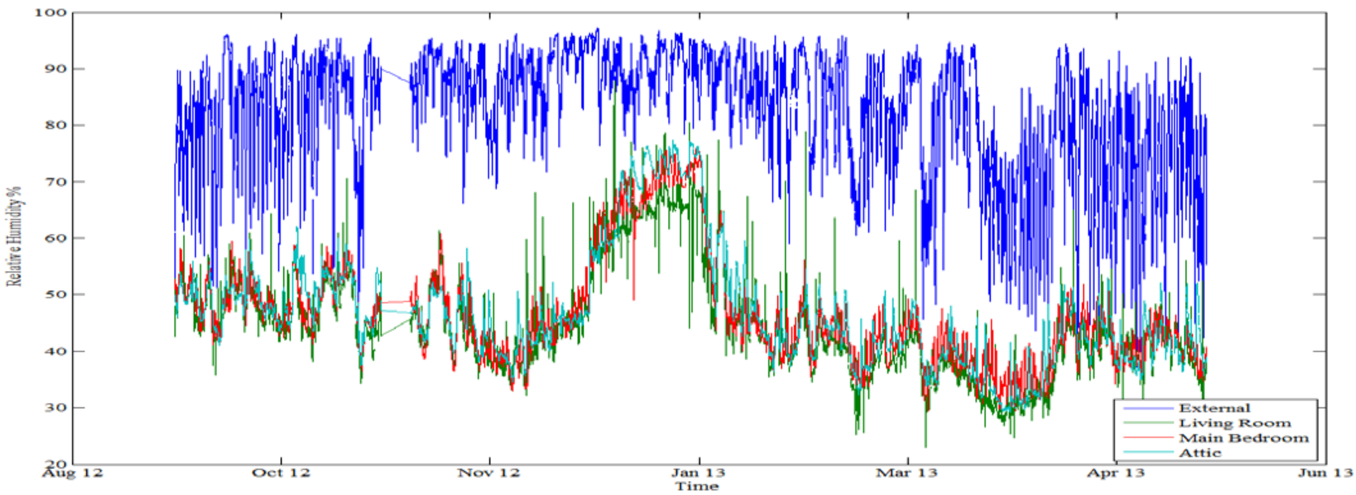


Figure 3. Relative humidity (%) measurements from September 2012 to May 2013

The maximum internal temperature was recorded in the attic room at 25.80˚C slightly exceeding the comfortable temperature range. However temperature in this room exceeded 25˚C less than 0.1% of the time and had a mean temperature of 19.44 ˚C. The main bedroom had a temperature range of 18.30˚C to 25.60˚C with a mean of 21.26˚C. The living room had a similar temperature range of 17.51˚C to 24.60˚C and a mean of 21.17˚C. Overall internal temperatures during the monitoring period are within a desirable range and are relatively stable despite varying external temperatures, indicating that the thermal envelope is performing well. It should be noted that these figures do not include monitoring during the summer period as the data was not available at the time of writing.

Humidity levels are found to have a wider range with peaks particularly found in the living room where the max of 87.89% was recorded. After closer inspection of monitored data it was found that this peak was recorded when the house was unoccupied over the Christmas period. When the house is unoccupied a minimum ventilation rate of 0.05 – 0.1 l/s.m^2 as recommended by BS EN 15251:2007 (British Standard, 2007) is required. The MVHR does not have such a low ventilation rate and so as to reduce unnecessary energy consumption a timer which turned on the system for 20 minutes every hour was installed. If the heat exchanger temperature drops below a set point the MVHR system turns off. The combination of the unoccupied house not providing warm internal air to the heat exchanger and the low external temperatures resulted in the MVHR remaining turned off thus causing a build-up of internal humidity. The mean humidity levels for the living room, main bedroom and attic indicate there is no risk of the development of mites or mould growth at 44.66%, 46.51% and 46.93% respectively. In all three rooms humidity exceeded 70% less 1% of the time indicating that the MVHR is effectively removing moisture from the house.

Indoor temperature and humidity levels for the three rooms were found to be similar in the IES-VE model. A mean temperature of approximately 20˚C was recorded in the three rooms with maximum temperature of 25.09˚C estimated in the living room. Humidity levels predicted in the model compare favourably with the monitored results with the largest range of 14% to 85% predicted in the attic and mean humidity level of 44% in the three rooms.

3.2 Energy consumption results

Household electricity and gas consumption for the domestic hot water and space heating and electricity generated by the photovoltaic panels were recorded in the house. As electrical appliance use patterns are often difficult to establish this paper focuses on the energy consumed by DHW and space heating and results are summarised with modelled results in Table 2 below. The actual monitored results and modelled results are relatively close, with only approximately 10% difference in space heating and 5% in domestic hot water. Gas conversions from the measured m^3 to MWh was based on the calorific values listed in Department of Energy & Climate Change (2013b).

Table 2. Summary of modelled and monitored and

	Pre-retrofit Modelled (MWh)	**Post retrofit Modelled (MWh)**	**Post retrofit Actual (MWh)**
Domestic hot water	2.066	1.6952	1.624
Space heating	29.5786	2.8388	2.594

As the model results compare well for energy consumption and internal conditions future climate change weather files inserted into the model.

5. MODELLING CLIMATE CHANGE

Two weather files types are available from the Prometheus project, as discussed by Eames et al. (2010), Test Reference Years and Design Summer Years. Test Reference Year (TRY) weather files are made up of months from different years and do not contain extreme heat-waves therefore are considered unsuitable for overheating risk assessment. Design Summer Years (DSY) are used for summer overheating assessment only and are based on average temperature of the summer months at the centre of the upper quartile of rankings obtained from approximately 20 individual years. As discussed in Coley et al (2012) the statistical basis of DSY weather files is not as robust as TRY weather files therefore only TRY weather files are considered in the paper.

The climate data for UKCP09 is issued as a probability density function resulting in a range of percentiles; 10,33,50,66 & 90. It is important to note as explained by DEFRA (2012), that these probabilities are subjective having been estimated from the strength of existing information and are not objective estimates that account for all possible results. In this paper the high emissions scenario (A1F1) will be modelled for 2030, 2050 & 2080 for the 10th and 90th percentile and compared to current conditions. It has been assumed that settings for MVHR system, DHW hot water demand and minimum internal temperature have remained the same for all simulations.
The effect of future climate on internal conditions and energy consumption for the case study are shown in Figure 4 and Figure 5 respectively.

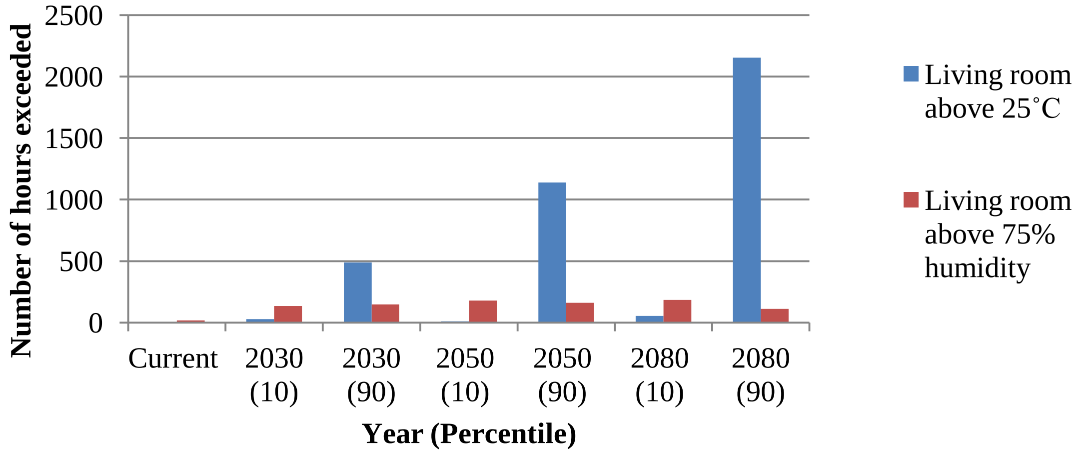


Figure 4. Number of hours where temperature and relative humidity exceed desirable range

The number of hours for which temperature exceeds 25°C and relative humidity exceeds 75% in the living room is shown to steadily increasing from negligible current levels to high levels for the 2080 90% probability. These calculations do not take account the use of the 'summer by-pass', night-time purging or changed occupant behaviour and are likely to be conservative.

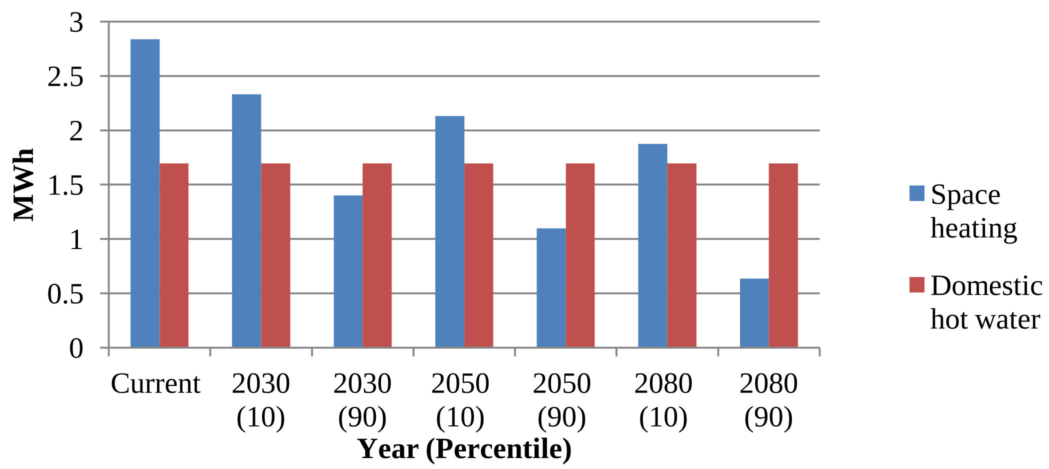


Figure 5. Space heating and domestic hot water requirements in current and changing climate

Figure 5 shows the annual energy consumed in space heating and domestic hot water in the house. It can be seen that the relative importance of space heating is decreasing whilst domestic hot water stays constant. This raises some potential questions for the current retrofit hierarchy which focuses predominately on improvement of building envelope. Space cooling measures have not been included in the simulation but are likely to be required given the high number of hours that internal temperatures exceed the desirable criteria.

6. CONCLUSIONS

This paper presented the monitoring results of a low energy retrofit in Northern Ireland which has been occupied for one year. Measurements of temperature and relative humidity have shown that the house has a comfortable internal environment. Actual energy consumption for space heating and domestic hot water compared well with modelling completed in the IES-VE program. The model showed significant savings in energy consumption pre and post retrofit. The use of future weather files simulating potential climate change have highlighted issues that should be studied further including the following:

- reducing space heating demand through retrofit measures is vital to reduce domestic energy consumption and associated emissions but measures implemented should consider the future service life of the building particularly in a changing climate.
- internal conditions of retrofit projects could be detrimentally affected in a changing climate with over-heating and high humidity likely.
- ventilation systems require careful specification and monitoring of performance to ensure healthy indoor environment in air-tight buildings.

Analysis of the monitoring data is being used to continually improve the performance of the retrofit and ensure a comfortable internal environment for the occupants. It is hoped that the results of this monitoring will help better inform others of the effectiveness of retrofit measures implemented and long term performance.

REFERENCES

British Standard, 2007. BS EN 15251:2007 "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics", London: British Standards.

Chartered Institution of Building Services Engineers, 2006. "Environmental Design Guide A", 7th Edition., Norwich: CIBSE Publications.

Collins, L., Natarajan, S. & Levermore, G., 2010. "Climate change and future energy consumption in UK housing stock. Building Services Engineering Research and Technology", 31(1), pp.75–90..

Department for Environment, Food & Rural Affairs (DEFRA), 2012. "UK Climate Projections - What is meant by probability in the UKCP09 probabilistic projections? ". Available at: http://ukclimateprojections.defra.gov.uk/21680

Department of Energy & Climate Change, 2013a. "Energy consumption in the United Kingdom". Available at: https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/energy-consumption-in-the-uk.

Department of Energy & Climate Change, 2013b. "Digest of United Kingdom energy statistics (DUKES) 2013". Available at: https://www.gov.uk/government/publications/digest-of-united-kingdom-energy-statistics-dukes-2013-printed-version-excluding-cover-pages

De Wilde, P. & Coley, D., 2012. "The implications of a changing climate for buildings", Building and Environment, 55, pp.1–7.

Eames, M., Kershaw, T. & Coley, D., 2010. "On the creation of future probabilistic design weather years from UKCP09". Building Services Engineering Research and Technology, 32(2), pp.127–142.

Hacker, J. & Holmes, M., 2007. "Thermal comfort: climate change and the environmental design of buildings in the United Kingdom", Built Environment, 39 (7), pp802-814.
Low Energy Building Database (2011) "Project Overview". Low Energy Building Database. Available at: http://retrofitforthefuture.org/
World Health Organization Europe, 2009. "WHO Guidelines for Indoor Air Quality: Dampness and Mould", Elisabeth Heseltine and Jerome Rosen, ed., Germany: Druckpartner Moser. Available at: http://www.euro.who.int/__data/assets/pdf_file/0017/43325/E92645.pdf